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Cryobots: An Answer to Subsurface Mobility in Planetary Icy Environments

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Exploration of the deep subsurface ice sheets of Earth, Mars, Europa, and Titan has become a major consideration in addressing scientific objectives in climate change, extremophile biology, exobiology, chemical weathering, planetary evolution and ice dynamics. This sort of exploration on Earth has been accomplished through ice coring, for chemical and crystallographic analysis, and sounding radar, for structural analysis, and the results from these studies have been of high value, most recently in elucidating the temporal and circulation aspects of climate change on Earth. For some applications, coring and remote sensing techniques are not optimal; these applications include situations in which the ice cores are too warm for successful core retrieval, investigations which require strict sterilization, and planetary environments for which in-situ observations are the extent of exploration technologically possible. We will discuss test results and design issues including the fluid dynamics of hot-water jetting, approaches to maintaining vertical attitude, tether management.

The cryobot concept is based on the Philberth thermal probes sponsored by the US Army in the 1960's. The Philberth probes were 3-4meters long and consumed 3-4kW during descent operations. The primary method of descent used a heated tip to melt through the ice. A control system using a mercury level bath to maintain a vertical orientation passed through to the multi heater nose sections. The cryobot in seeking to improve on the Philberth probe, employs a method of hot water jetting to drill into the ice. The ice drilling community has been using electro-mechanical drilling and hot water jet drilling successfully for many years. Hot water jet drilling has been a very effective method to gaining access below the ice sheets due to drilling fast, straight holes. Past tasks at JPL have also influenced the development of the cryobot. A mission study, CHIRPS, began defining vehicle size, mass, and power necessary for applications to Europa exploration. The hydro-thermal volcanic vent probe projects helped define instrument packaging and environment constraints on a probe which operates in liquid environments where extreme temperatures and pressures are found.

An icy moon orbiting Jupiter has revealed an environment which re-ignites the imagination for the possibilities for life on other worlds. The daunting question, in response to this discovery, was how to explore this complex world. Europa, orbiting the

Jovian environment with high radiation exposure, has an icy shell several kilometers thick and below a possible salty ocean several kilometers deep. A possible answer to this challenge is a cryobot or subsurface thermal probe to explore this icy world. As luck would have it, there is an Earth analog to the Europa environment. Subglacial lakes exist on Earth's polar regions which lie under +4km thick ice sheets. This is of great interests to scientists seeking to explore the ice and liquid environments to characterize not only the European environment but also to aid in the understanding of our planet. Another fascinating planetary body also currently scrutinized for the possibility of liquid water and life is Mars. Recent missions have kindled a growing interest in the Martian polar caps. Polar missions have been of great interest as climate history is likely recorded in the largest observed reservoirs of water and ice on Mars, the ice caps. Ice flow, sublimation, sediment deposition, and wind erosion are believed to be the most important processes that shape the caps, however, little remains known about the composition, porosity, density, and layering of Mars polar ice. Due to the cryobot's unique method of mobility, the polar ice can be possibly penetrated and scientific studies conducted.

Scientists are eager to employ the cryobot to study such relevant scientific objectives as Earth paleocirculation and ice dynamics science, Europa ocean and ice in-situ exploration, and Mars climate history, exobiology, and operational access to water. The mix of strong Earth and planetary science interests is crucial in supplying testing opportunities at terrestrial sites for robotic systems to be used in planetary applications with costs shared among agencies and programs.

Due to ice structure variability with depth, the thermal probe vehicle would need to adapt to varying environmental conditions during descent. An example of this on Earth ice sheets is firn ice at the surface with increasing density with depth. The Cryobot must be capable of motion through ice, which is coldest on the upper surface and gradually warms at greater depths and pressures. The vehicle must also be capable of mobility through a liquid water environment as the probe would be surrounded by water in the melt cavity. Martian polar ice has been seen to contain varying amounts of dust in a layered composition. Ice on Europa and Titan is thought to have an ionic composition. Therefore the Cryobot must be able to proficiently melt through ice containing varying concentrations of dust, sediment, and possible ionic compositions.

The Cryobot moves by melting ice in front of (below) the vehicle and descending. As the Cryobot moves, it is in a lozenge-shaped volume of water, which is freezing at the top as ice melts at the bottom. The Cryobot contains many distinct features for its success and development. The probe will have a hybrid of active and passive melting systems. This will be done through combining a heated tip, a water heating subsystem, and a jetting subsystem. Hot-water drilling relies on hot water being forced against a melting front so that there is enhanced heat exchange as well as the sweeping away of granular material. The combination of passive and forced turbulent melting should address the principal problems, and modern techniques of microfluidics, monitoring, telemetering, and control will aid in improving design elements.

The basic structure of the cyrobot vehicle is cylindrical and divided into Bays: Tether, Electronics, Instrument, Pump, and Nose. The tether used to supply power and serve as a data and command communication cable is spooled out of the vehicle during its descent into the ice and currently designed to store 500meters of tether. The electronics and instrument bay uses a pressure housing very common to oceanographic probes. The pump bay contains the water jet system and the nose bay is the passive melting system. The vehicle must be controlled to maintain vertical orientation during passive melting. The system needs to engage water jet drilling and adjust for varying environmental conditions. The instrument suite will have to coordinate with the vehicle system for data and sampling collection. A simple ground station is used for commanding the probe and recording the data telemetry.

The modeling performed for vehicle melting was thermodynamic and fluid dynamic analysis. The first step was to characterize passive melting dynamics. The next step was to understand water jet melting dynamics and develop performance parameters. We desired to have predictable performance and optimal performance capability. These parameters were compared with a matrix of tests thus creating a set of performance parameters to define the baseline design of the vehicle. System tests were completed to characterize the overall performance of the prototype vehicle and evaluate the performance of various subsystems